CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-230

EUREKA PEAK and Related Faults
Joshua Tree South and Yucca Valley South Quadrangles
San Bernardino and Riverside Counties, California

by
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INTRODUCTION

The June 28, 1992 M_S7.5 Landers Earthquake was accompanied by ground rupture along several well known faults, as well as rupture along some previously unknown faults. The most extensive "new" faulting occurred in two zones south of the Pinto Mountain fault, in and southeast of the town of Yucca Valley. The purpose of this report is to document the newly identified faults and to assess other features so that Special Studies Zones may be established in accordance with the Alquist-Priolo Special Studies Zones Act (Hart, 1990). The faults described are located on the Yucca Valley South and Joshua Tree South 7.5-minute quadrangles (see Figure 1).

SUMMARY OF AVAILABLE DATA

The only faults previously known in this immediate area, south of the Pinto Mountain fault, were a concealed fault along Lower Covington Flat (informally called here the "Lower Covington Flat fault") and some northwest-trending faults to the south (Dibblee, 1967; see Figures 4a & 4b). These faults are mapped within pre-Cambrian gneissic rocks and Mesozoic granodiorite. Where Quaternary alluvium is present the faults are shown as concealed. The two "new" faults are known only from the recent surface rupture. Post-earthquake trenching has provided evidence of prior Quaternary displacement (Rasmussen, 1992; see discussion on page 7). Although Dibblee (1967) did not map a fault where the Eureka Peak fault has been identified, he did map a granodiorite body with an irregular contact that crosses the fault. In hindsight, this irregular boundary can be explained as the offset margins of the granodiorite (Figure 4b). If this interpretation is correct, then there has been a total of approximately 500m of right-lateral displacement along this fault since its inception.

The Pinto Mountain and Morongo Valley faults, which are not part of this study, are included in a Special Studies Zone on the Yucca Valley South quadrangle (Figure 4a) and have been described and assessed by Bryant (1986). This prior study did not assess recent faulting south of these two westerly trending structures. A description of triggered slip on the Pinto Mountain fault from the Landers earthquake is included in a more recent study by Bryant (1992).

SEISMICITY

The Landers earthquake was preceded by the April 22, 1992 Joshua Tree earthquake which is now recognized as a foreshock to the June 28 event. Figure 2a shows seismicity associated with the June 28, 1992 Landers earthquake. The zone of seismicity clearly delineates a deeper north-northwest trending crustal structure which is overlain by the northwesterly-trending *en echelon* fault pattern of the western Mojave Desert. It is notable that the zone of seismicity extends well south of the zone of surface rupture, across the Pinto Mountain fault. The only observed effect that the Pinto Mountain fault may have had on this pattern is that the aftershocks do not appear to extend as deep in the region south of the fault as they do to the north (E. Hauksson, oral presentation, 8/27/92), and there is a slight decrease in density of epicenters at the fault crossing (Figure 2b). Aftershocks to the Landers earthquake have been common in the area southeast of Yucca Valley. The Eureka Peak and Burnt Mountain faults are closely associated with this zone of aftershocks (octagons on Figure 2b). Most prominent was a M5.7 aftershock which occurred in Yucca Valley approximately three minutes after the main shock and which propagated southward for approximately 11km (Hough et al, 1992).

There is also an apparent north-trending zone of aftershocks to the Joshua Tree earthquake (crosses on Figure 2b). The seismicity pattern suggests that the Joshua Tree earthquake was on a different (but closely related) structure from the Eureka Peak fault. Rymer (1992) refers to the source structure for the Joshua Tree earthquake as the West Deception Canyon fault. The northern part of this zone was not noticeably active after the Landers earthquake and does not correspond with any known or inferred structure at the surface. Two clusters of aftershocks to the Joshua Tree earthquake occurred along the southern projection of the "Lower Covington Flat fault", however no surface rupture has been reported along that fault.

AERIAL PHOTO INTERPRETATION

Three sets of aerial photos were used: BLM at 1:30,000, USDA at 1:20,000 and I.K.Curtis at 1:6,000 (see list at end of this report). Only the BLM photos cover the entire area of the two quadrangles surveyed. The photos were studied for evidence of recent faulting. Because the faults that recently ruptured were poorly expressed in the aerial photography, other lineaments of similar strength of expression have also been noted for analysis, but they are by no means considered to be necessarily equally active. These lineaments fall into four main sets: north-northwest & north trending, west-northwest & northwest trending, northeast trending, and east-west trending (see Figures 3a & 3b).

NNW & N trending lineaments:

The recent ground rupture is associated with north or north-northwest trending structures. The **Eureka Peak fault** is moderately expressed in the older terrain by a linear margin of a ridgeline, several straight stream channels and some vegetation lineaments (Figure 3b). Within the Late Quaternary fan deposits, however, it was nearly invisible until the Landers earthquake. A few short linear ridges or northwest oriented hillocks north of Juarez Drive (Figure 3a) suggest structural control, but these features were not associated with rupture in the June 28 earthquake. Only some very subtle, and discontinuous, west-facing scarps are, in hindsight, associated with this structure in the younger alluvial fans. None of the features associated with this fault would have previously led to recognition of this fault as a Holocene structure. Fault line features are generally irregular and eroded. A prominent linear canyon one mile east of the Eureka Peak fault is parallel to that fault and may be similarly active although it lacks the same apparent continuity.

The topographic expression of the **Burnt Mountain fault** is better and slightly more continuous. Features seen in air photos were also confirmed in the field. The most prominent expression is a west-facing escarpment in the alluvium north of Burnt Mountain. This scarp has been preserved by being within a "depositional shadow" north of Burnt Mountain. A vegetation lineament observed along the southwest side of Burnt Mountain is visible in all photos except the 1952-3 USDA photos which were taken too soon after a fire for the lineament to appear. A small sidehill bench can be seen in the most recent large-scale photos. A southern continuation is indicated by a subtle north-south trending linear ridge in older alluvium, aligned truncated spur ridges, and a straight canyon margin further south (see Figure 3a).

Similarly oriented lineaments in East Wide Canyon and Long Canyon crosscut, and are probably younger than, most of the west-northwest structures. They consist principally of linear drainages and tonal contrasts (characteristics which could merely be fault-line features) and they appear to be offset at their northern ends by some of the west-northwest trending lineaments. The East Wide Canyon lineament is nearly on trend with the Burnt Mountain fault and may be controlled by a fault which is, or once was, a continuation of that fault. The trend of this feature, on the Yucca Valley South quadrangle, is clearly defined by the prominent linear northern portion of East Wide Canyon. It is also marked by tonal contrasts and an eroded west-facing scarp. Although there are no features within this quadrangle suggestive of Holocene displacement, the lineament continues to the south (in the Seven Palms Valley 7.5-minute quadrangle) where drainage patterns are clearly affected and minor surface rupture occurred in April 1992 (see discussion on page 8). The Long Canyon lineament displays no evidence of Holocene displacement.

WNW & NW trending lineaments:

The oldest-appearing lineaments trend west-northwest and seem to be truncated or displaced by other lineaments. They consist principally of aligned linear drainages and saddles with some tonal and vegetational lineaments. There are no features indicative of Holocene displacement. In the western part of the Yucca Valley South quadrangle (Figure 3a) these structures verge toward a more westerly orientation. All of these features are probably fault line features or are controlled by joints or other lithologic contacts.

The northwest-trending **"Lower Covington Flat fault"** is generally indicated by the linearity of the canyon, some subtle scarps in the alluvium, and some small, isolated hills along the northeast margin of the canyon. The alluvial scarps may be merely the result of stream erosion and other features are not clear enough to indicate youthful movement. Many of the features, particularly at the southern end of the fault (near Smith Water Canyon), are eroded and breached by modern drainages which show no subsequent deflection or narrowing. The entire structure appears to be associated with a canyon which is part of a very old landscape. There is no geomorphic indication that it is still active.

NE trending lineaments:

A few northeast trending features, aside from the Pinto Mountain and Morongo Valley faults, appear to be old, probable fault-line features. Two prominent NNE lineaments, in the northwest part of the Yucca Valley South quadrangle, are subparallel to the Morongo Valley fault. One includes a clear but degraded scarp and shows no effects on younger drainages which cross it. Drainages across the other show renewed incision which has migrated upstream. A pair of more easterly-trending lineaments consist mostly of aligned saddles.

E-W trending lineaments:

Some east-west trending structures, on the Joshua Tree South quadrangle (Figure 3b), appear fresher than most but do not continue out of the bedrock areas into the alluvium and therefore are of uncertain age. The most prominent of these is a backfacing scarp in sections 31 and 36 at the northern margin of the quadrangle. The clarity of this feature is probably a result of the resistance of the quartz monzonite. A minor drainage across this scarp has breached the scarp, suggesting that it is not as young as it might appear on aerial photos.

FIELD OBSERVATIONS

Several newly identified faults, as depicted on Figures 4a & 4b, were mapped based on ground rupture observable in the field. The ground rupture was mapped on the I.K.Curtis 1:6000-scale aerial photos. Some of the fault rupture is visible in these photos. Where photo coverage was not available mapping was done on the 1:24,000 topographic map or 1:20,000 USDA aerial photos. Field work was done between June 29 and July 17, September 14-16, and on November 10, 1992. Mapping of the Eureka Peak fault within the Joshua Tree National Monument was done along with Michael Rymer of the U.S. Geological Survey.

Eureka Peak fault - This 10.5 kilometer long fault is named for "Eureka Peak", which is near the southern end of the fault. Eureka Peak is a local name based on the "Eureka" benchmark located on this highpoint in the Little San Bernardino Mountains. The Eureka Peak Trail (not shown on map) follows the fault trace for much of its length along a canyon within the Joshua Tree National Monument. North of the Monument the fault follows along the western margin of a broad wash which drains Lower Covington Flat. It is interesting that the fault along this stretch is largely at the top of the wash margin or in the bank, with the west side down, suggesting that the location of the wash is not related to this fault. Near its northern end the fault bifurcates, the eastern branch being generally better defined. The western branch is more diffuse, comprising a zone almost 100m wide. A slight graben has formed between the eastern and western splays. The maximum right-lateral displacement of 21cm was measured just south of the Monument boundary. Lateral displacement diminished to the north to less than 10cm where the fault divided into two splays, and became two zones of *en echelon* cracks at the northernmost end. To the south, displacement diminished to less than 10cm at about 2 kilometers into the Monument and less than 1cm within a zone of left-stepping cracks at the southern rupture terminus (M. Rymer, personal communication, August 1992). Measured vertical displacements were as much as 5cm, but greater displacement could be concealed within local warping.

Burnt Mountain fault - This north-south zone of surface rupture extends southward for 6 kilometers, from just south of Highway 62, across Burnt Mountain (for which it is named), and into Joshua Tree National Monument. Except across Burnt Mountain, the fault ruptured within older alluvium. The northern half of the rupture is comprised of nearly a continuous zone of left-stepping *en echelon* fractures with one somewhat wider step south of Burn Mountain. Southward from Section 12 the surface rupture is less continuous and at the southernmost end of the rupture zone was only apparent where bedrock spurs projected out from the canyon side. The width of the zone is typically less than 1 meter wide, but in places measured as wide as 5 meters. The maximum lateral displacement was 5.5cm right-lateral. Vertical displacement was consistently down to the west, but varied in magnitude up to 5.0cm. Greater vertical displacement may be masked by broader warping which was evident in some areas. Displacement, at both the north and south ends of the mapped fault, diminished to discontinuous left-stepping cracks with no measurable displacement.

Unnamed fault of Dibblee (1967) along Lower Covington Flat - Field inspection of this concealed and inferred fault (called here the "Lower Covington Flat" fault) following the June 28 Landers earthquake found no surface rupture other than a short (<1km) zone of left-stepping cracks near its northern end. Magnitude of displacement was not measurable; however the clearly left-stepping nature of the cracks indicates minor right-slip. No cracks were observed or reported along this fault when it was checked following the April 22 Joshua Tree earthquake.

Cross Fault Southeast of Burnt Mountain - A short (0.5 km) northeast-trending, left-lateral cross fault, southeast of Burnt Mountain, had minor rupture (<2.0cm) within a zone of widely right-stepping fractures.

East-West fault - An unnamed fault(?), within Sections 31 and 36 at the northern margin of the Joshua Tree South quadrangle, was initially identified by its sharp appearance on aerial photography. Field inspection showed this feature to be relatively degraded and to lack any evidence of cracking. Steeply-dipping joints and shears in bedrock exposures are generally parallel to the feature. The scarp and sidehill bench are breached in several places by short drainages. The sidehill bench retains alluvium which has some minor soil development indicated by reddish coloration and clay skins on sand grains.

AFTERSLIP

The Eureka Peak fault has been the only fault which has had continued slip after the principal rupture occurred on June 28. Afterslip, as measured across a quadrilateral array near San Andreas Rd., has added approximately 40 mm (as of 11/7/92) to the total displacement at this location (initial displacement was not measured at this site, but was probably on the order of 20 cm). Roughly half of the afterslip occurred during the first two weeks following the M7.5 mainshock and the slip rate has diminished logarithmically (personal communication, Art Sylvester, UCSB). Creepmeters installed near Pueblo Trail, Juarez Drive, and San Andreas Road, although installed later, have recorded nearly 15 to 17 mm of afterslip as of 10/26/92 and show a similar logarithmic decay (written communication, Roger Bilham, Univ. of Colorado). All three creepmeters recorded an episode of increased slip following a small cluster of aftershocks (M4.8 and smaller) on August 15, 1992. A similar, but more abrupt, slip event on September 15, 1992 appeared to be associated with a M4.7 aftershock and a series of at least 18 smaller shocks located southeast of Yucca Valley. Right-slip varied from about 0.5 mm at Pueblo Trail to nearly 3.0 mm at San Andreas Rd. Other afterslip episodes are recorded only on the two more southerly creepmeters.

The Burnt Mountain fault appears to have had at least some afterslip as well. Fresh-appearing pavement cracks, part way across Joshua Lane, were first observed on September 15, 1992 (the same day as the recorded abrupt slip episode on the Eureka Peak fault). Offset of a white line along the northern margin of the road was approximately 1 mm. By November the pavement cracks had extended and a reference mark painted on the road indicated 1-2 mm of additional right-slip.

DISCUSSION AND CONCLUSIONS

The region covered by the Yucca Valley South and the Joshua Tree South quadrangles includes several fracture sets, some clearly older than others. The most recently active fracture zones are parallel to the north and north-northwest trend of the underlying seismicity. It appears that the deeper zone of seismicity has driven the ground rupture along several overlying surface faults which are, in some cases, oblique to the underlying structure. The recently active **Eureka Peak** and **Burnt Mountain** faults appear to be related to the Johnson Valley fault to the north based on the continuous zone of seismicity that underlies them (Figure 2b). They may also be related, respectively, to the West Deception Canyon and East Wide Canyon faults to the south (M. Rymer, personal communication based on work in progress).

Considering that the Eureka Peak and Burnt Mountain faults showed no prior surface indication of Holocene displacement, some additional criteria have been sought to judge other features in this area. The various strong lineaments have been discussed relative to their orientation and association with known active faults. Faults with a north or north-northwest trend are considered likely to respond to the same stresses as those which caused ground rupture on the Eureka Peak and Burnt Mountain faults. These stresses are also considered to be more likely to accumulate where instrumentally recorded seismicity shows that deformation is already occurring.

Eureka Peak fault

This fault has several geomorphic indicators of prior displacements, although none are fresh enough to indicate prior Holocene activity. South from Machris Park the fault clearly defines the western flank of a narrow ridge, and further south, within the Monument, the fault has formed small scarps and has controlled the location of an unnamed wash. Other evidence, however, which may indicate prior Holocene activity comes from recent (post-earthquake) trenching (Rasmussen, 1992). Trenches across the western branch and its subsidiary traces, south of Onaga Trail, found evidence of at least two prior late-Pleistocene events, based on displacement of two buried paleosols. The higher of the two buried soils is estimated to be late Pleistocene to early Holocene in age. From his trench observations Rasmussen (1992) estimates a possible recurrence interval approaching 11,000 years.

The recent (June 28, 1992) surface rupture along the Eureka Peak fault appears to be, at least in part, coseismic. A resident at the northern end of the fault zone reported seeing ground rupture form across their back yard within the first minute of ground shaking. This seems to have happened prior to the M5.7 aftershock that occurred approximately 3 minutes after the main shock and which propagated south from Yucca Valley (Hough et al, 1992).

The Eureka Peak fault may be related to the "West Deception Canyon fault" to the south. This latter fault is cited as the source of the April 22 Joshua Tree earthquake (Rymer, 1992). The aftershocks which define the northern part of this fault zone (see Figure 2b), however, do not line up with the Eureka Peak fault or the Landers aftershock sequence. (The "West Deception Canyon fault" had no surface rupture and is not well defined as a surface feature).

<u>Burnt Mountain fault</u>

The Burnt Mountain fault has clearly been active in the past and is, in fact, more clearly expressed in the late Quaternary deposits than is the Eureka Peak fault. The distinct west-facing scarp north of Burnt Mountain would probably have been sufficient evidence to zone at least the northern portion of the fault, if it had been previously mapped. Although rupture occurred through a subtle sidehill bench on Burnt Mountain, this fault location is apparent only in hindsight. Without the recent ground rupture the fault expression to the south would have been even more ambiguous. At the southernmost end of the rupture it was apparent that displacement at depth in the bedrock could only propagate up through the Quaternary alluvium where spurs protruding from the sides of the canyon brought bedrock nearer to the surface. Similar spur ends define at least one more fault segment to the south of the recent rupture zone (Figure 3a).

<u>East Wide Canyon fault</u>

This fault was tentatively named the West Wide Canyon fault by Rymer (1992) but has been renamed by him (personal communication, November 1992) because it follows the East Wide Canyon drainage and its tributaries more closely. The East Wide Canyon fault is apparent as a bedrock structure which has controlled the erosion of the East Wide Canyon drainage. Quaternary activity is indicated by the topographic expression of the fault in the Seven Palms Valley quadrangle to the south where a major tributary drainage has been offset and a ridgeline has blocked two broad canyons. Minor triggered right-lateral slip (max. 6mm lateral, 4mm vertical within a 1½km interval) has been reported, also to the south, along the East Wide Canyon fault as a result of the April 22 Joshua Tree earthquake (Rymer, 1992; note that the fault name has been changed from the original reference as the <u>West</u> Wide Canyon fault). The triggered slip, which occurred entirely to the south of the mapped area, demonstrates the continued accumulation of right-lateral stress. This fault is oriented the same as, but offset from, the active Burnt

Mountain fault to the north. The area which had triggered slip overlies the western edge of the southern aftershock zone (see Figure 2b).

Long Canyon lineament

The only other structure which has a similar trend to those which have recently ruptured is the prominent lineament along Long Canyon. Although sharing the north trend with the other structures considered to be active, this probable fault lies further west than the others from the distinct zone of seismicity and has not had any triggered slip or other indication of accumulating stress.

"Lower Covington Flat fault"

The inferred fault mapped by Dibblee (1967) along the east margin of Lower Covington Flat (Figure 4b) is the probable controlling structure of this valley. This broad drainage is beheaded just south of the quadrangle boundary (Figure 4b) and, like Upper Covington Flat, appears to be part of an old, perhaps pre-Quaternary, landscape. The fault is apparently part of the older set of WNW and NW trending faults. Some activity of the fault, into the Quaternary, is suggested by the eroded scarps at Smith Water Canyon (Figure 3b) although the scarps appear to be facing the wrong way. The recent rupture near the northwest end of this fault is probably due to a pre-existing zone of weakness which has transmitted stress locally where it overlies the prominent zone of recent seismicity. Because of its location and orientation it could be expected to have similar minor rupture in association with a future rupture event on the Eureka Peak fault.

Cross fault

The northeast-trending cross fault that ruptured in June 1992 is a not-too-surprising response to the probable clockwise rotation of Burnt Mountain between the two larger right-lateral faults. There was no surface indication of prior movement of this fault, but it could be expected to respond similarly to a future rupture event along the Eureka Peak or Burnt Mountain faults. Because of its apparent relation to these two faults it is not likely to move independently.

East-west fault(?)

A fault in sections 31 & 36 at the north margin of the Joshua Tree South quadrangle is suggested by a prominent south-facing scarp and sidehill bench across a steep hill of quartz monzonite. This possible fault, although among the sharpest features observed in the aerial photographs reviewed, appears older when viewed from the ground. Its apparent clarity is due to the resistance of the bedrock; however it has been breached in several localities by small drainages, a task which must have required a significant interval of time. It is possible that it is not even a primary tectonic feature. The steep adjacent slope to the north and the well-developed shears and joints in the bedrock may have allowed this feature to develop as a shaking effect in response to an earthquake on any of several nearby faults.

RECOMMENDATIONS

The Eureka Peak fault, the Burnt Mountain fault, the cross fault, and the local zone of rupture near the north end of the "Lower Covington Flat fault", as mapped on Figure 5, should be included within Alquist-Priolo Special Studies Zones. These faults are sufficiently active and well defined based on the June 28 coseismic surface rupture and additional geomorphic and tonal features.

The well-defined portion of the East Wide Canyon fault on the Yucca Valley South quadrangle, as shown on Figure 5, should also be included in a Special Studies Zone, based on the triggered slip observed along this fault further to the south. The portion of this fault on the Seven Palms Valley quadrangle should be included in a Special Studies Zone at such time as that quadrangle is involved in re-evaluation for zoning. The fault is within the National Monument and a delay in zoning to the south should not have an adverse impact.

No changes are recommended at this time to the existing Special Studies Zone along the Morongo Valley and Pinto Mountain faults. Other lineaments described in this report are not recommended for zoning as they are not sufficiently active.

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AERIAL PHOTOGRAPHS USED

I.K.Curtis

Landers EQ 92-1178	9x9 B/W	1:6000	
frames 1-1 to 1-9		9-30-92	
frames 2-10 to 2-20			9-30-92
Landers EQ 92-1226	9x9 B/W	1;6000	
frames 24-268 to 24-280		7-3-92	
frames 24A-281 to 24A-291			7-3-92

U.S. Bureau of Land Management

BLM CAHD-77	9x9 B/W	1:30,000
line 9-40 frames 5 to 11	9-13-78	
line 9-41 frames 1 to 7	10-26-78	
line 9-42 frames 1 to 6	10-26-78	
line 9-43 frames 1 to 6	10-26-78	
line 9-44 frames 1 to 8	10-26-78	

U.S.Department of Agriculture

AXL	9x9 B/W	1:20,000
frames 9K- 31 to 9K-36		11-18-52
frames 9K- 54 to 9K-59		11-18-52
frames 10K- 85 to 10K-96		11-18-52
frames 10K-110 to 10K-116		11-18-52
frames 38K- 40 to 38K-44		2- 4-53

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Rymer, M.J., 1992, The 1992 Joshua Tree, California, earthquake: tectonic setting and triggered slip: EOS, Transactions, Am. Geophysical Union, v.73, no.43, Fall Meeting supplement, p.363.

Treiman, J.A., 1992, Eureka Peak and Burnt Mountain faults, two "new" faults in Yucca Valley, San Bernardino County, California *in* Ebersold, D.B., ed., Landers earthquake of June 28, 1992, San Bernardino County, California, field trip guidebook: Southern California Section of the Association of Engineering Geologists, Annual Field Trip, October 10, 1992, p.19-22.

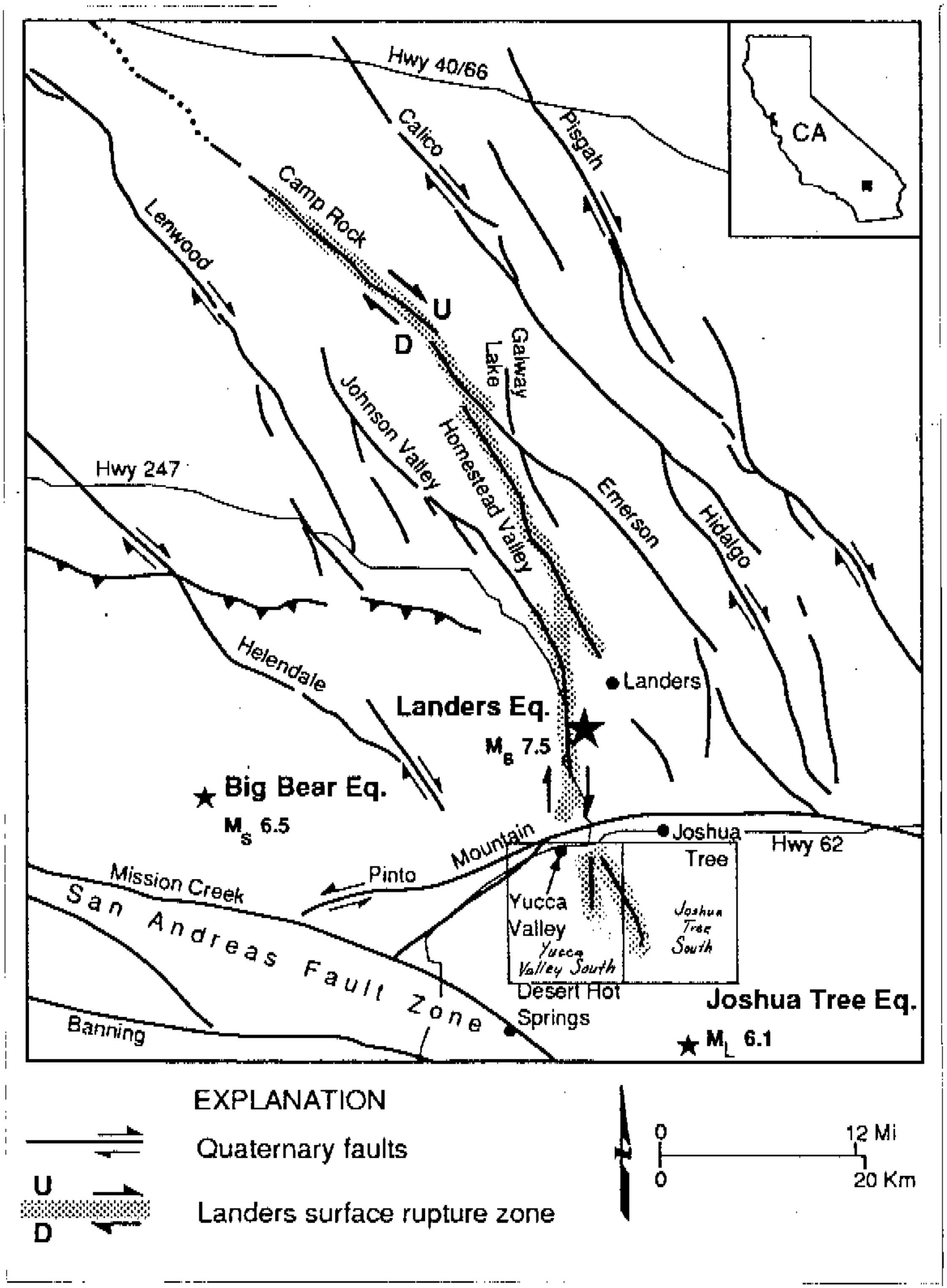

Figure 1 (FER-230) - Regional setting of the Yucca Valley South and Joshua Tree South quadrangles.

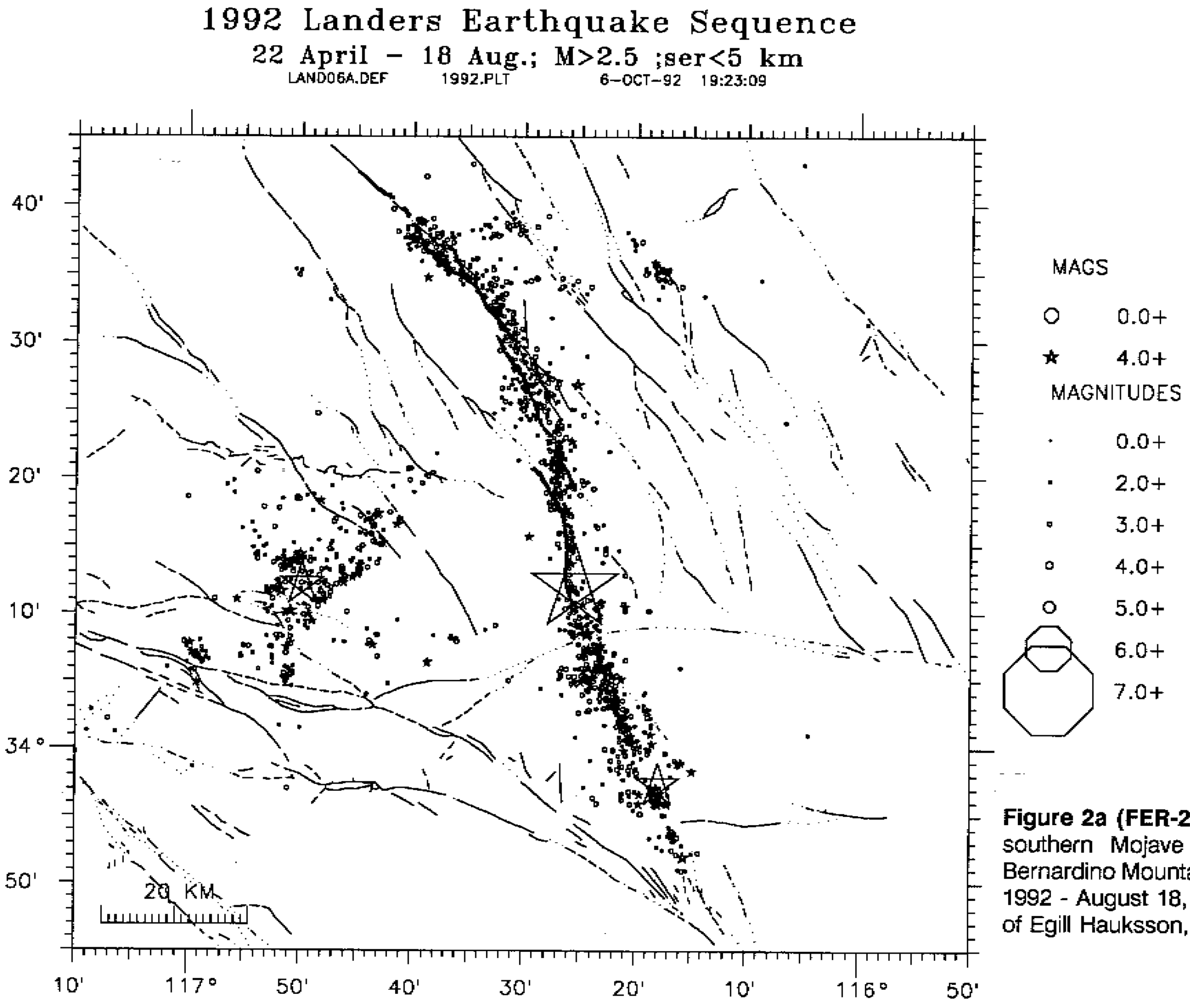

Figure 2a (FER-230) - Seismicity of the southern Mojave Desert / Little San Bernardino Mountains area from April 22, 1992 - August 18, 1992. (data courtesy of Egill Hauksson, CIT)

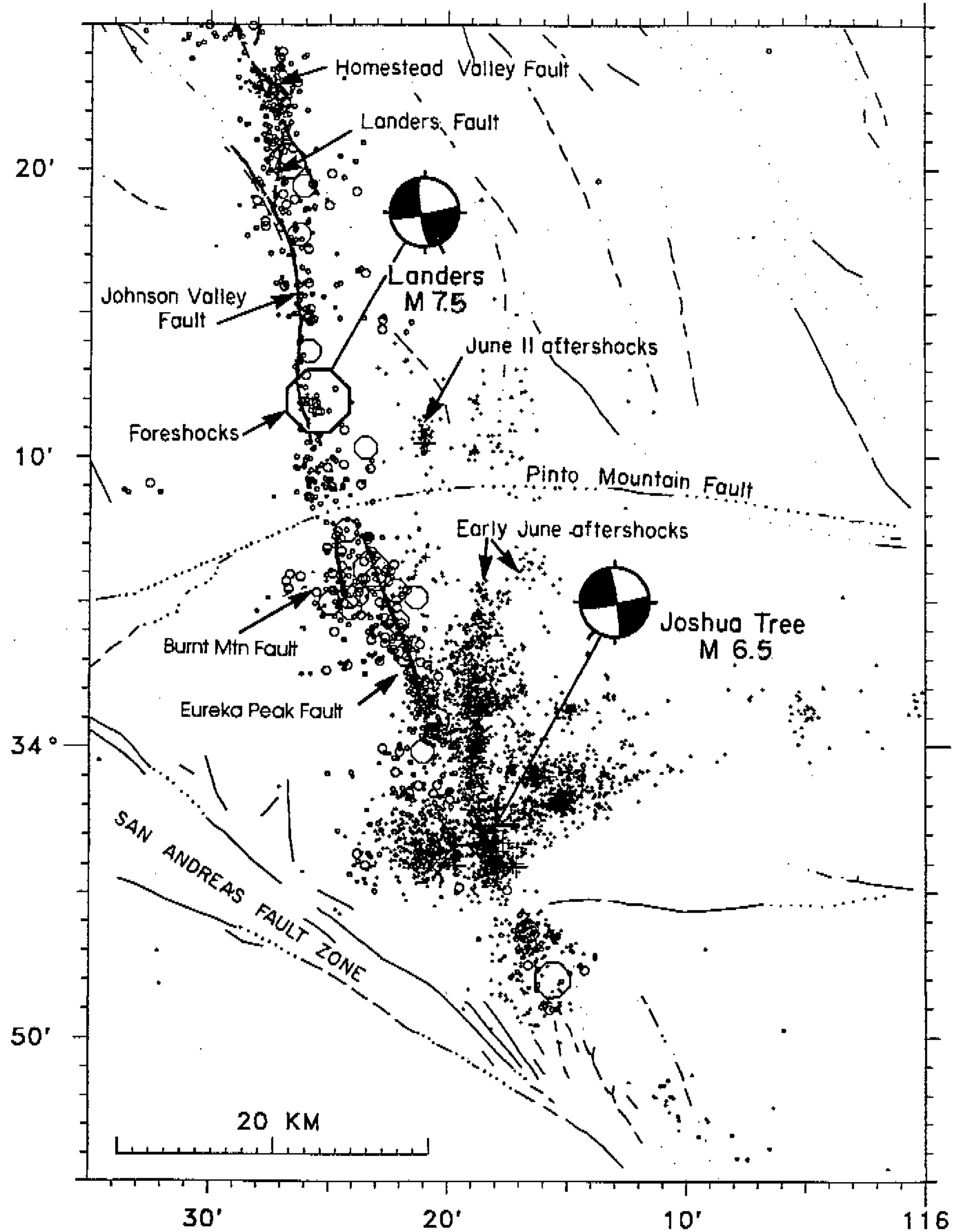

Figure 2b (FER-230) - Seismicity of the Joshua Tree region from January to August 18, 1992. Earthquakes before the Landers mainshock are shown by crosses; later events are shown by open circles. (from Landers Earthquake Response Team, 1992)